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Lloyd

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(54) **REGENERATIVE AIR BRAKE MODULE**

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B60T 13/00 (2006.01)

(52) **U.S. Cl.**
USPC **303/127**; 303/152

(58) **Field of Classification Search**
USPC 303/152, 127; 180/65.265; 701/71
See application file for complete search history.

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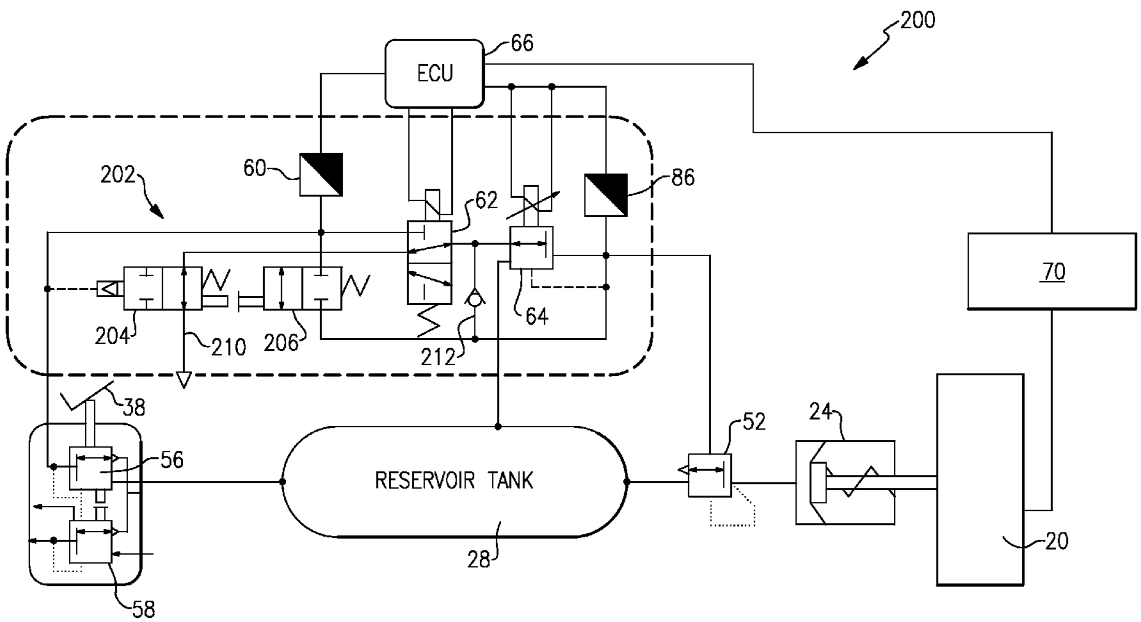
(74) *Attorney, Agent, or Firm* — Brooks Kushman P.C.

(57) **ABSTRACT**

An air braking system for a vehicle blends regenerative and foundation braking during low deceleration conditions in an effective and controlled manner. The braking system also includes a mechanical override that bypasses system electronics in response to an aggressive brake request such that treadle circuit pressure is sent directly to a brake relay circuit to actuate vehicle brakes.

26 Claims, 12 Drawing Sheets



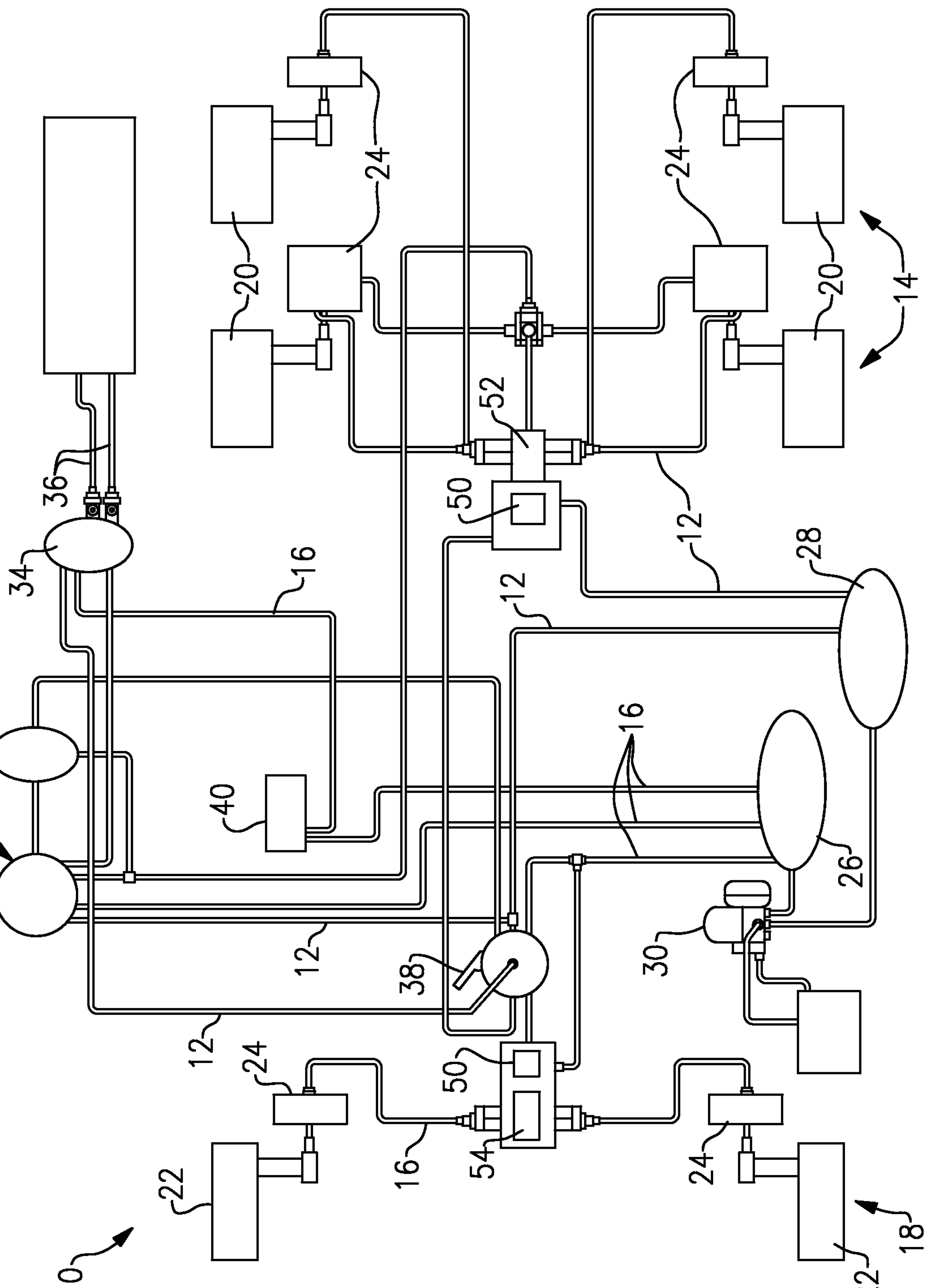


FIG.1

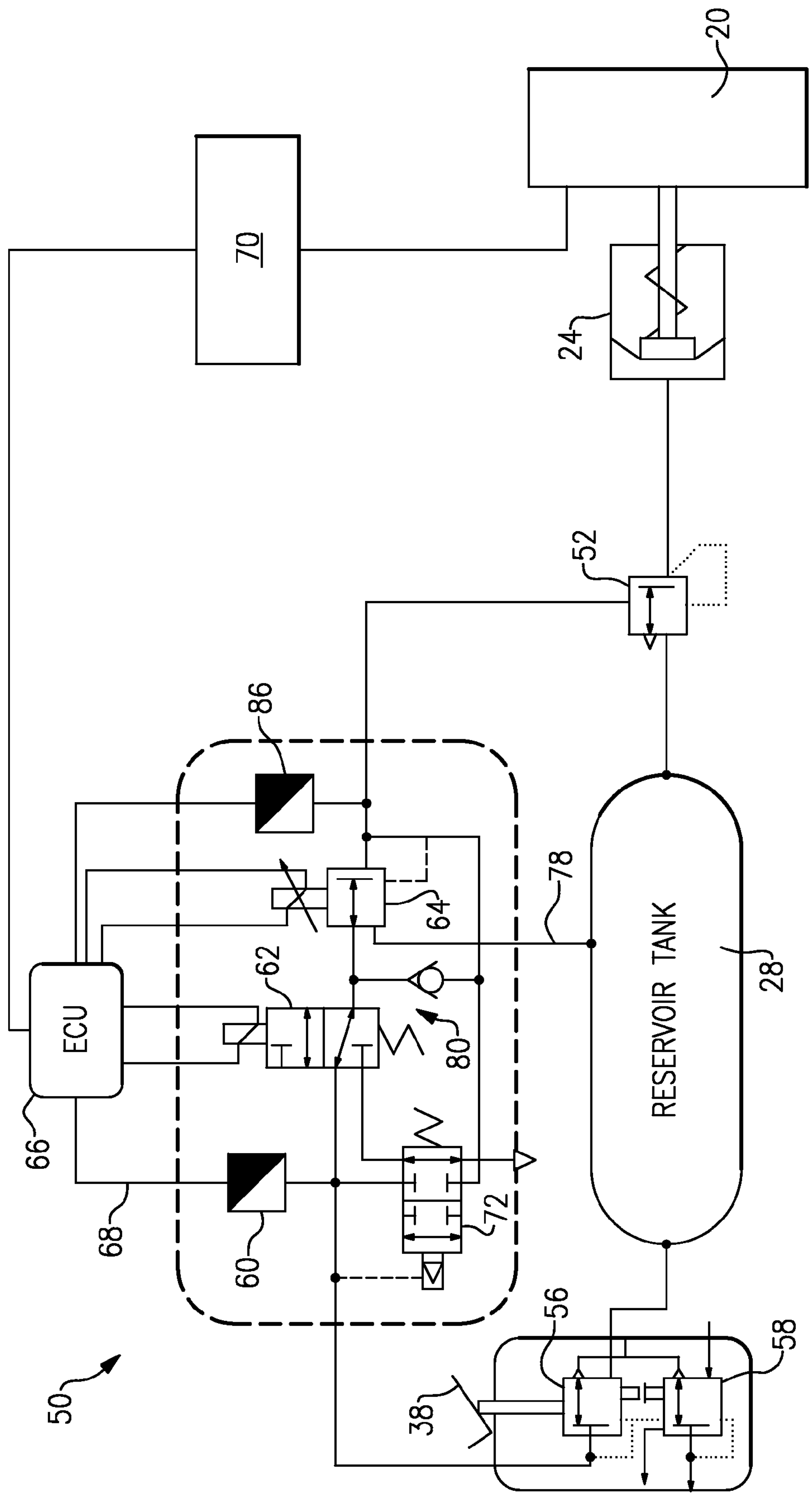

ECU
RESERVOIR TANK
70
20
24
52
86
64
78
62
80
28
66
72
68
60
56
58
38
50

FIG.2

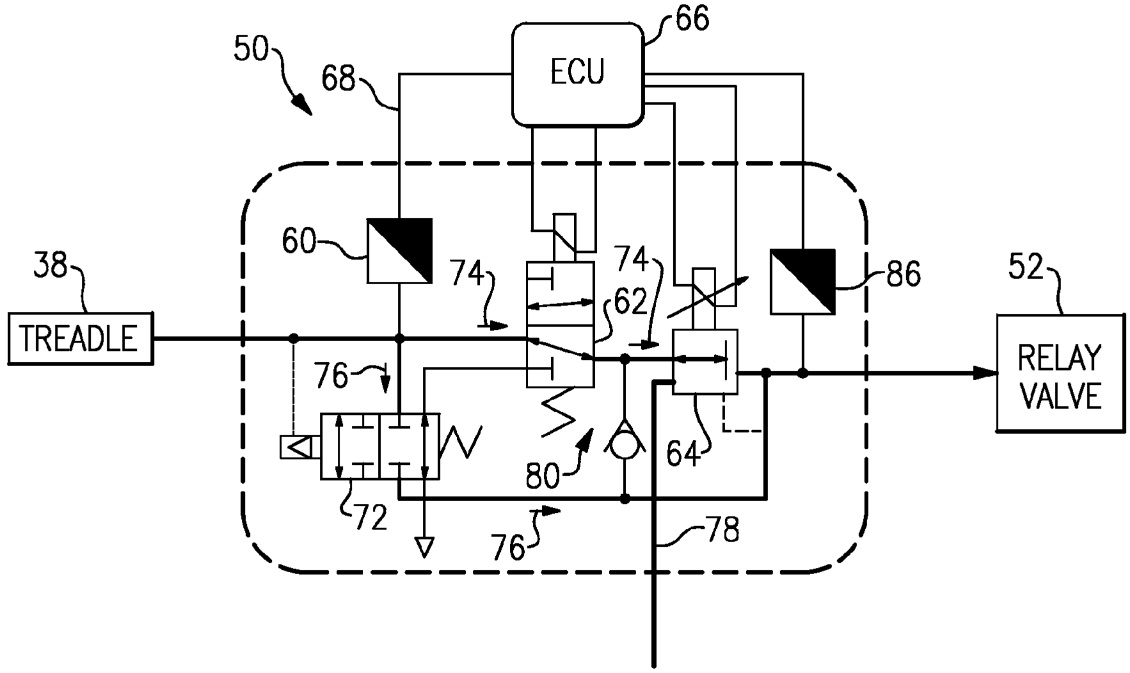

ECU
66
50
68
60
74
74
62
86
38
TREADLE
52
RELAY
VALVE
76
80
64
72
76
78

FIG.3

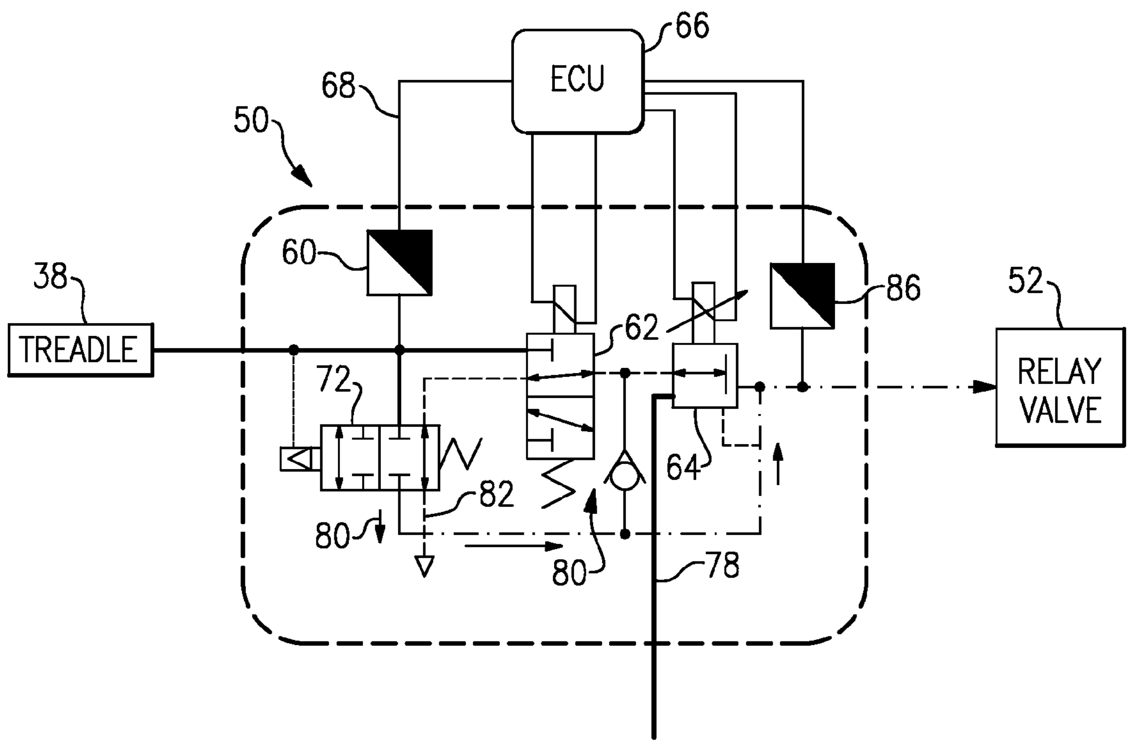

ECU
66
68
50
60
62
86
38
TREADLE
52
RELAY
VALVE
72
64
82
80
80
78

FIG.4

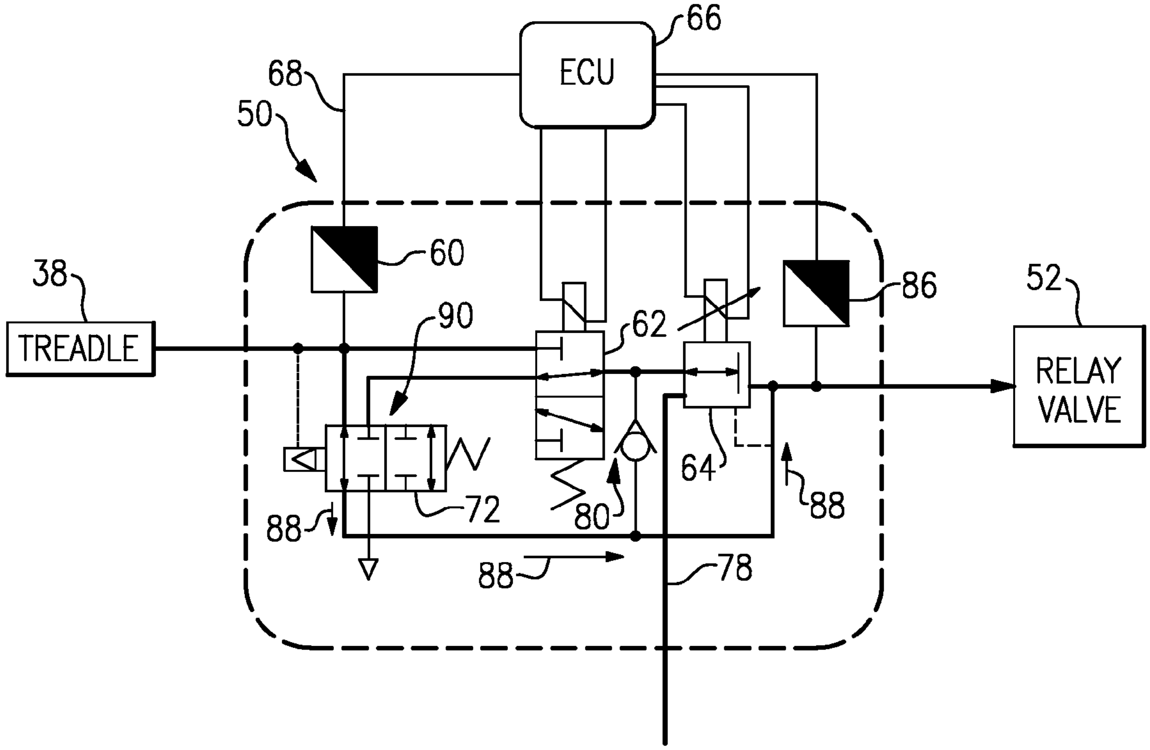
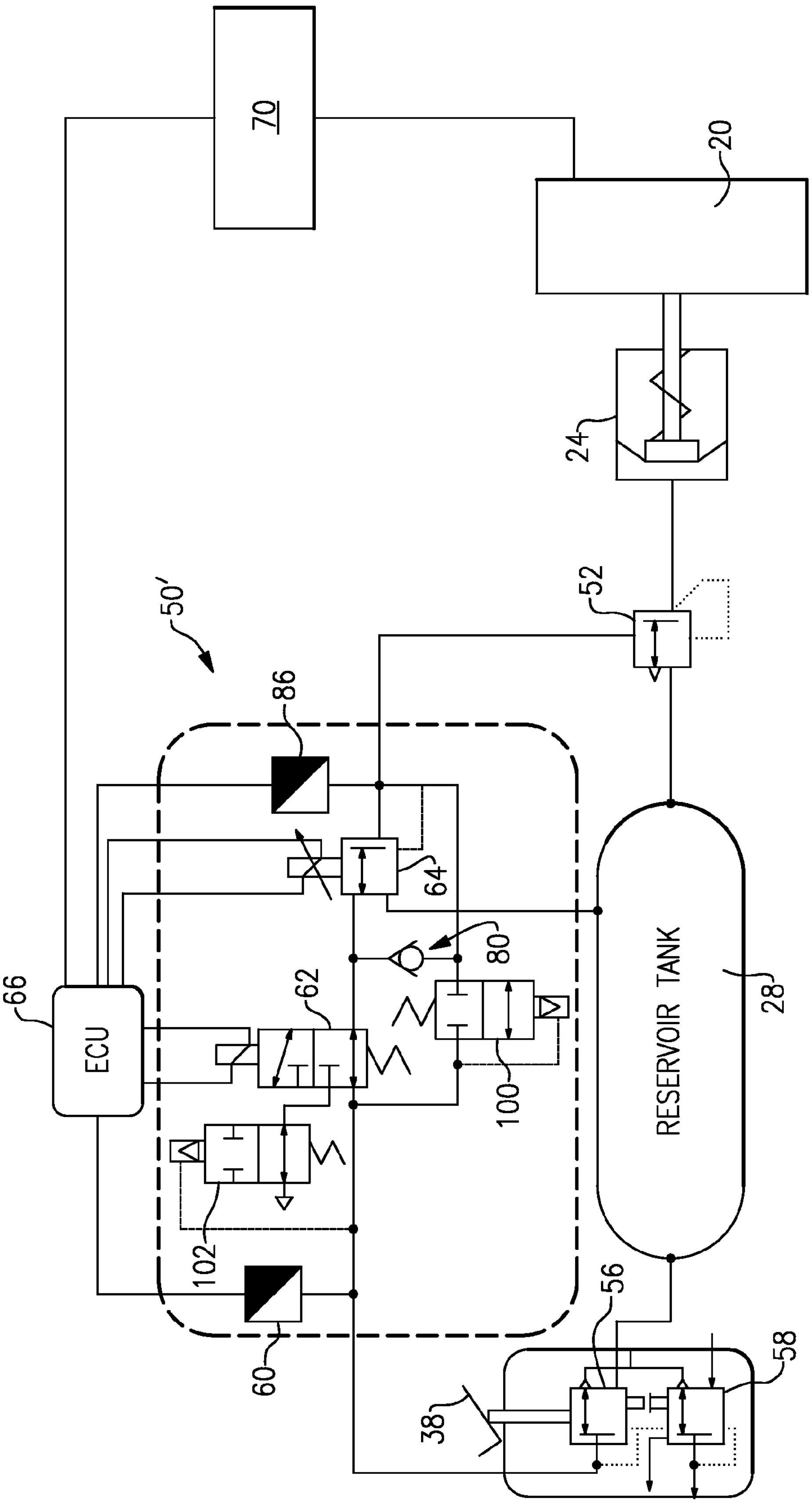

66
ECU
68
50
60
86
38
52
TREADLE
RELAY VALVE
90
62
64
72
80
88
88
88
88
78

FIG.5



70
20
24
52
50'
86
64
80
66
ECU
62
100
RESERVOIR TANK
28
102
60
56
58
38

FIG.6

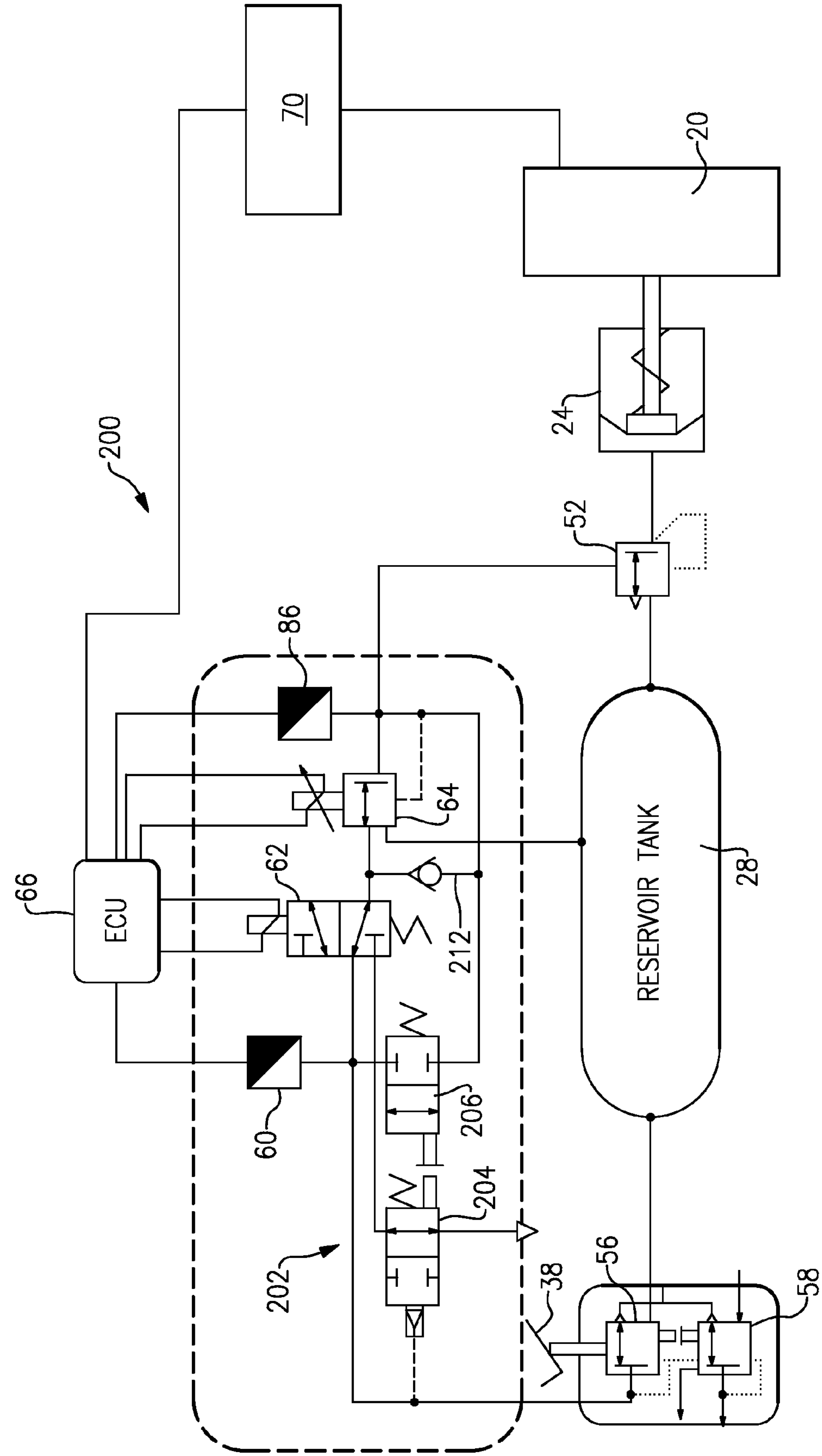
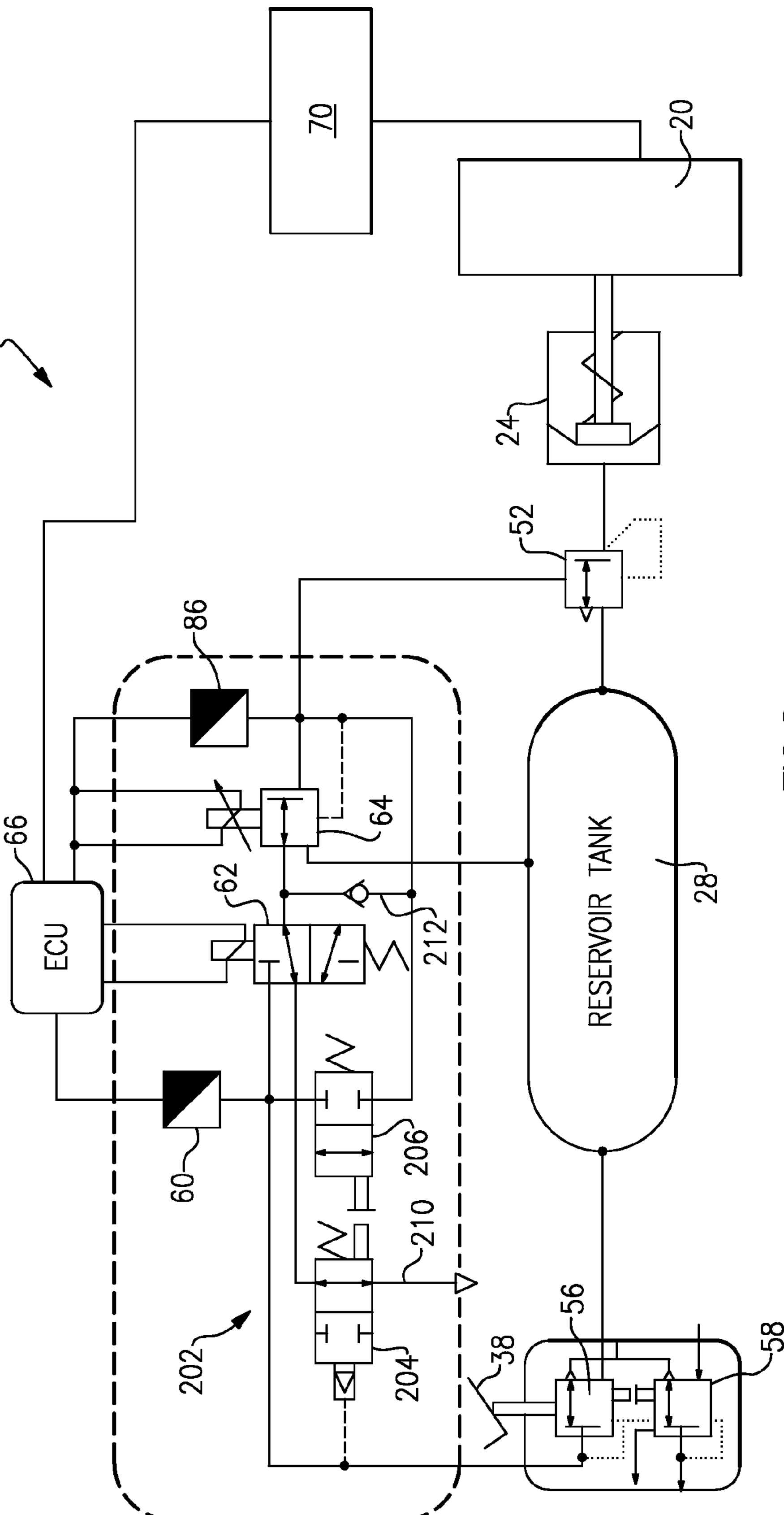

70
20
24
52
200
86
64
66
ECU
62
212
RESERVOIR TANK
28
60
206
204
202
38
56
58

FIG.7



200
70
20
24
52
86
66
ECU
64
62
212
RESERVOIR TANK
28
60
206
210
202
204
38
56
58

FIG.8

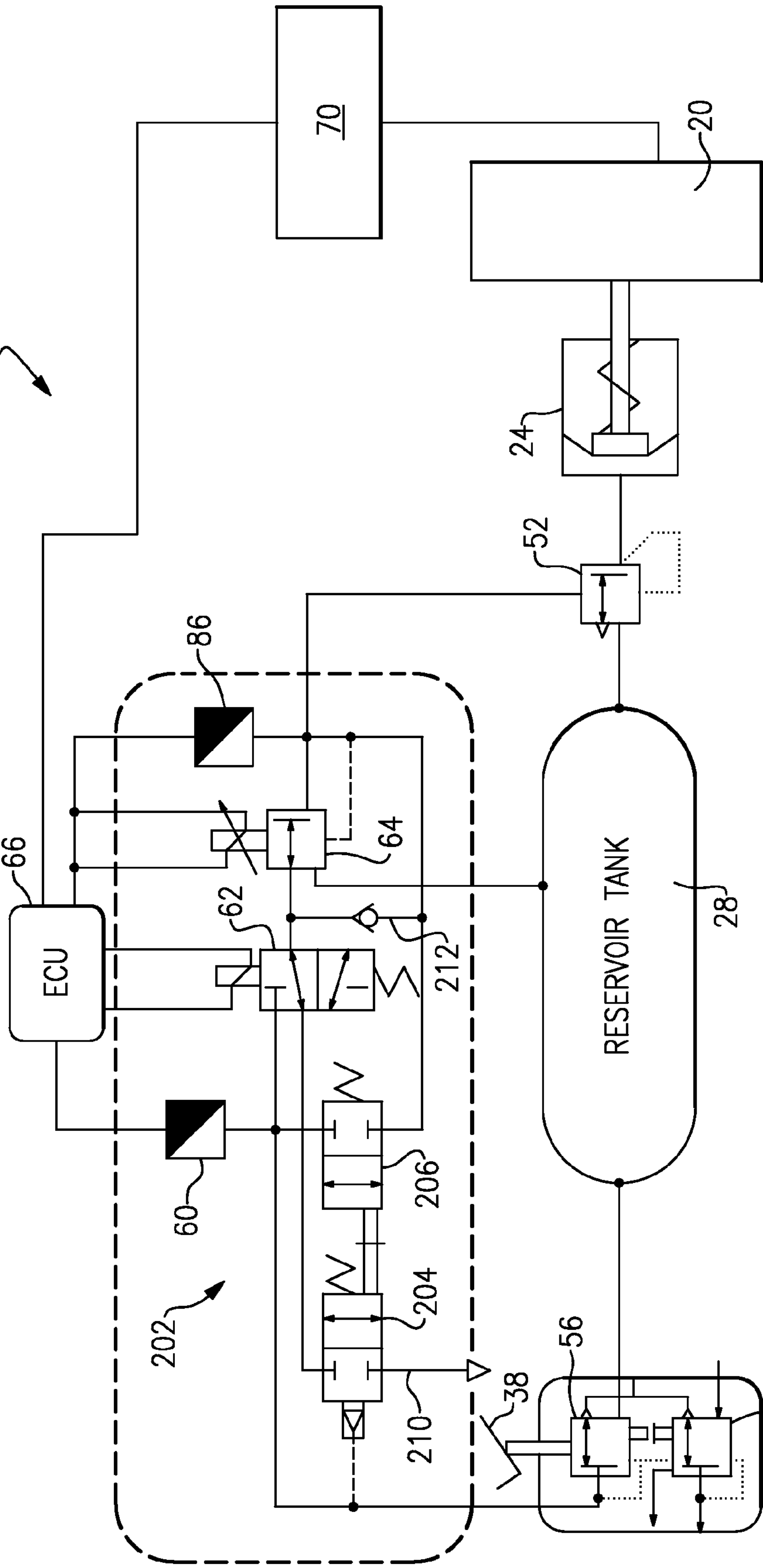

70
20
200
24
52
86
66
ECU
64
62
212
RESERVOIR TANK
28
60
206
204
202
56
58
38
210

FIG.9

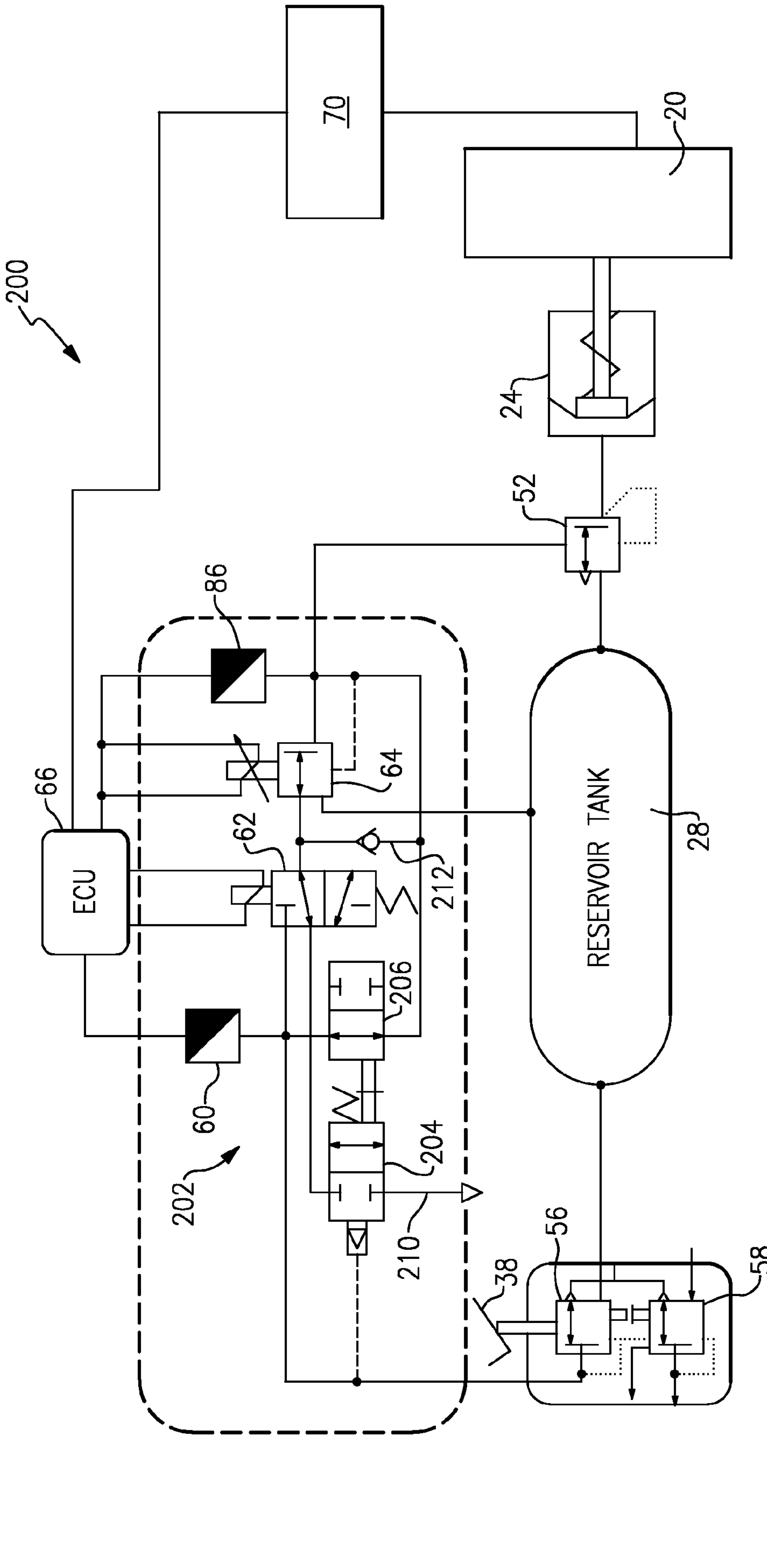

70
20
200
24
52
86
66
ECU
64
62
212
RESERVOIR TANK
28
206
60
204
202
210
56
38
58

FIG.10

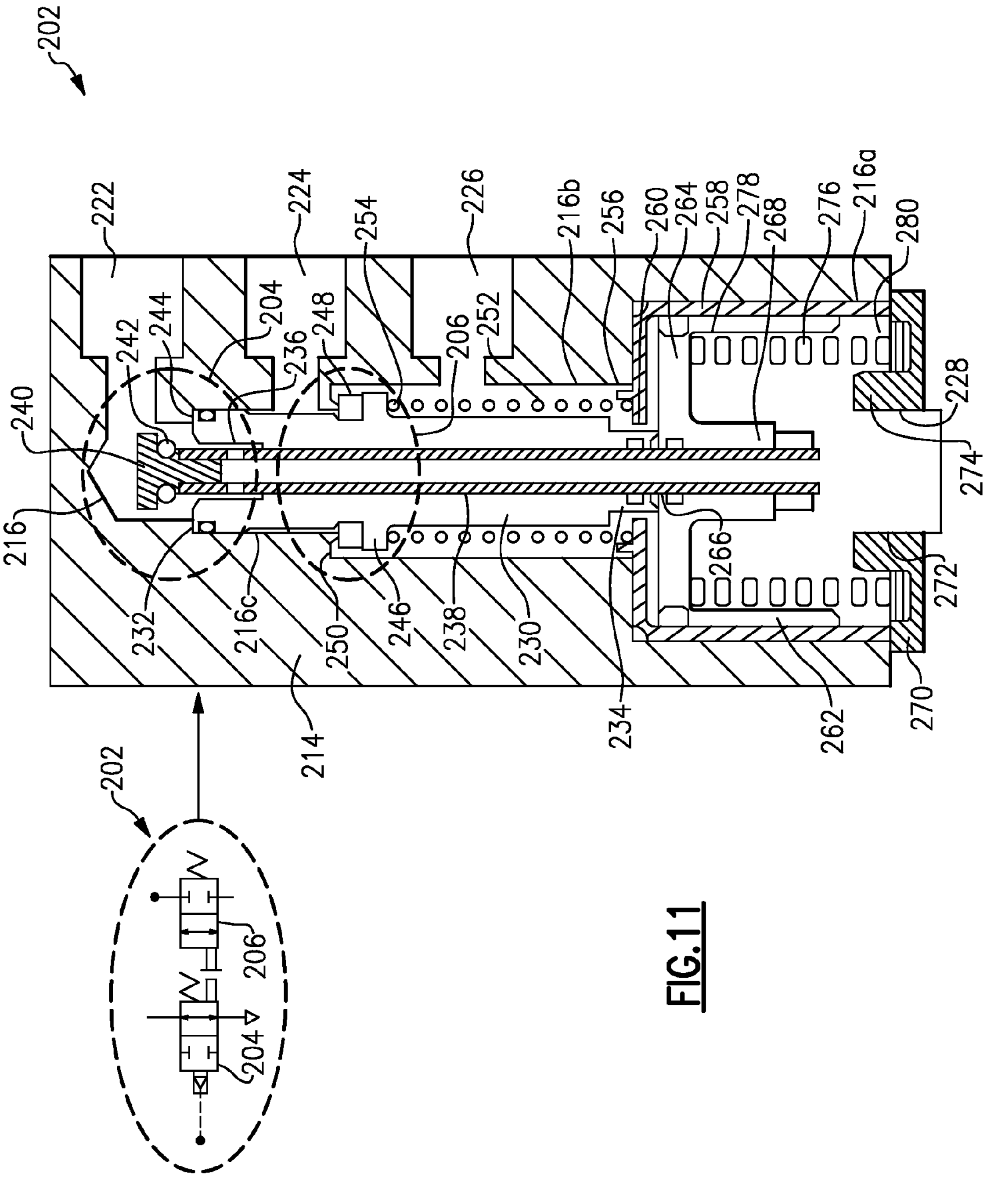

202
222
224
226
216b
256
260
264
258
278
268
276
216a
280
204
244
242
240
236
248
206
252
254
228
274
216
232
216c
250
246
238
230
234
266
272
262
270
214

FIG.11

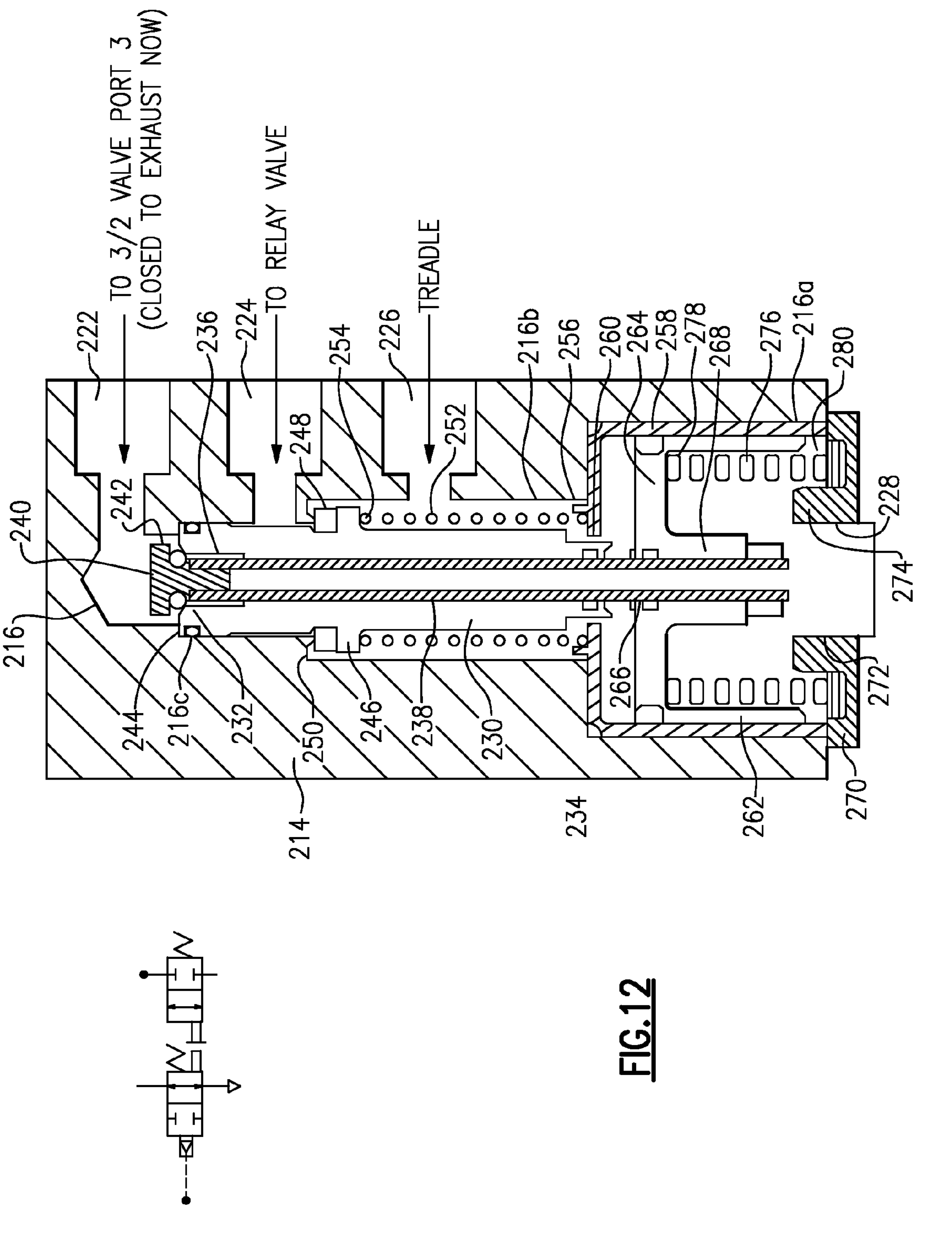

TO 3/2 VALVE PORT 3
(CLOSED TO EXHAUST NOW)
TO RELAY VALVE
TREADLE
222
224
226
236
254
216b
256
260
264
258
278
268
276
216a
280
228
274
272
270
262
234
214
216
240
242
248
252
244
216c
232
250
246
238
230
266

FIG.12

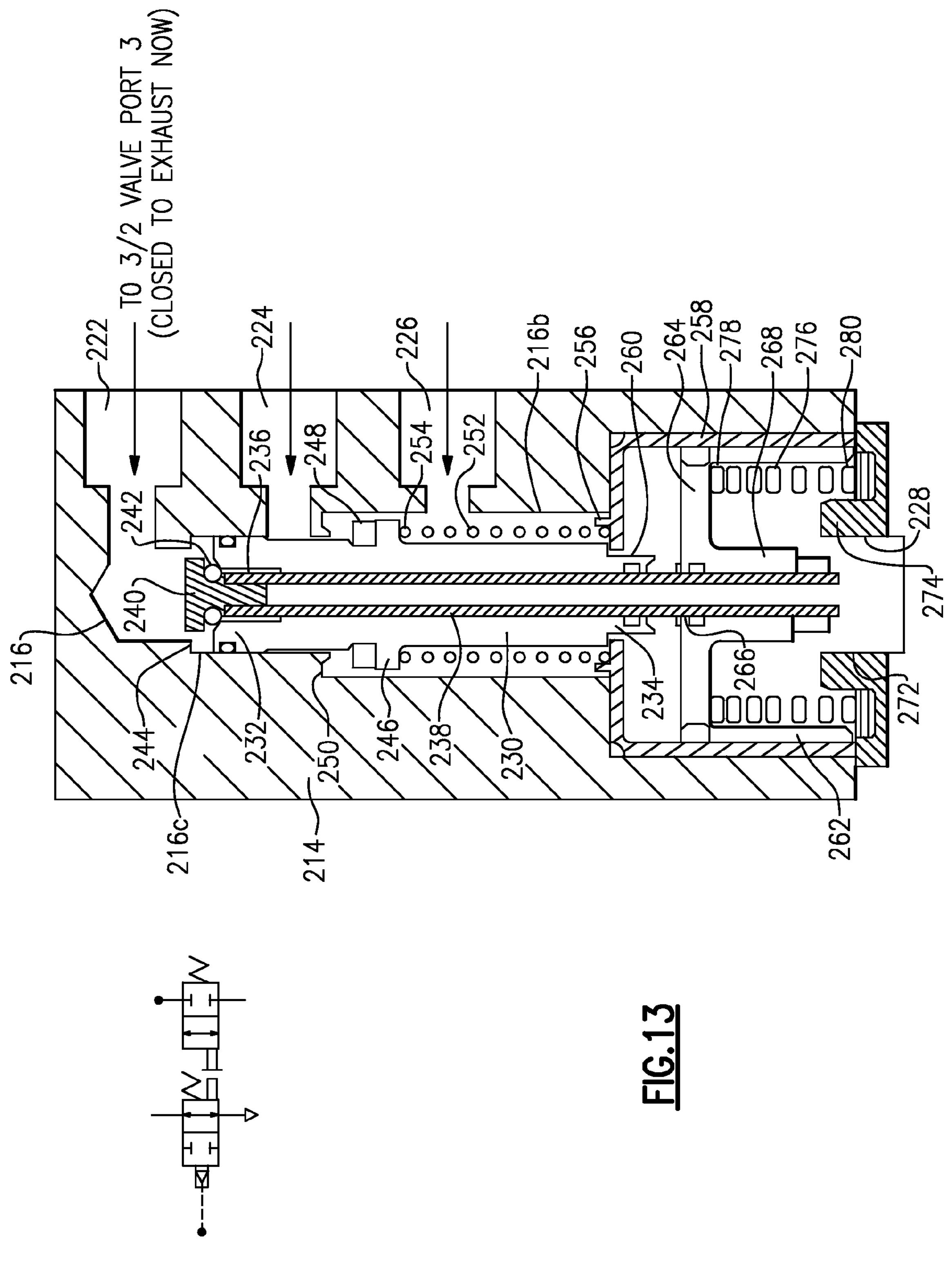

TO 3/2 VALVE PORT 3
(CLOSED TO EXHAUST NOW)
222
224
226
216b
256
260
264
258
278
268
276
280
236
248
254
252
242
240
228
274
216
244
232
250
246
238
230
234
266
272
216c
214
262

FIG.13

REGENERATIVE AIR BRAKE MODULE

TECHNICAL FIELD

This invention generally relates to a regenerative air brake module for a vehicle.

BACKGROUND OF THE INVENTION

Hybrid vehicles include an e-machine or other alternative power source which works in conjunction with an internal combustion engine to drive the vehicle. The vehicle includes traditional foundation braking and regenerative braking can also be provided by the alternative power source.

Hybrid vehicles recapture braking energy that would otherwise be lost as heat through foundation braking to improve vehicle operational efficiency. When regenerative braking is being performed, it is important that the vehicle operator's braking and handling "feel" be unaffected. To achieve this there should be controlled blending of regenerative and foundation braking such that the vehicle operator can operate the vehicle in a normal and predictable manner. Maintaining this feel for hybrid commercial truck braking systems presents even more challenges. Further, it is important that mechanical safety features be incorporated into the system in the event of a failure of the regenerative braking portion of the brake system.

SUMMARY OF THE INVENTION

An air brake system for a vehicle blends regenerative and foundation braking during low deceleration conditions in an effective and controlled manner. The braking system also includes a mechanical override that bypasses system electronics in response to an aggressive brake request such that treadle circuit pressure is sent directly to a brake relay circuit to actuate vehicle brakes.

The air brake system includes a brake input member configured to receive a brake request, the brake input member mechanically actuating a treadle valve of a treadle circuit having a treadle circuit air pressure. A sensor measures the brake request, and a controller is configured to determine a valve command based on the brake request from the sensor and based on a regenerative braking level. A control valve is configured to control a delivered air pressure level in a brake relay circuit based on the valve command, and the brake relay circuit is configured to communicate the delivered air pressure level to a vehicle brake.

In one example embodiment, the air braking system for a vehicle includes a treadle circuit with a treadle valve and a relay circuit with a relay valve. The treadle valve is associated with a treadle input that is actuated in response to a brake request. The relay valve communicates a delivered air pressure to a vehicle brake. A first pressure sensor measures a requested brake pressure from the treadle valve. A control valve is in a normally open position to directly connect the treadle circuit and the relay circuit during a first mode of operation. The control valve is operable to block treadle pressure in a second mode of operation. An electronic pressure regulator is configured to communicate treadle pressure to the relay valve when in the first mode of operation and is configured to communicate an air pressure less than the treadle pressure when in the second mode of operation. A controller is configured to generate a control signal based on the requested brake pressure and an available amount of regenerative braking. The control valve and electronic pressure regulator operate in the first or second mode of operation in response to the control signal to communicate the delivered air pressure to the vehicle brake. A mechanical bypass valve is operable to directly communicate treadle pressure to the relay valve when the requested brake pressure is greater than an override limit.

The first mode of operation is defined as a system "off" mode for standard air brake operation, and the second mode of operation is defined as a system "on" mode for regenerative braking operations at a condition where the requested brake pressure is less than a predetermined limit. When in the first mode of operation, the delivered air pressure is the treadle pressure, and when in the second mode of operation, the delivered air pressure is an air pressure that is less than the treadle pressure.

In one example, the air brake system includes a second pressure sensor that measures a delivered brake pressure to the relay valve and communicates the delivered brake pressure to the electronic control unit to provide a closed-loop system.

These and other features of the present invention can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of a vehicle brake system with a regenerative brake module.

FIG. **2** is a schematic representation of a regenerative brake module as used in the brake system of FIG. **1**.

FIG. **3** is the regenerative brake module of FIG. **2** in a system off condition.

FIG. **4** is the regenerative brake module of FIG. **2** in a system on condition.

FIG. **5** is the regenerative brake module of FIG. **2** in an aggressive braking condition.

FIG. **6** is another example of a regenerative brake module that can be used in the brake system of FIG. **1**.

FIG. **7** is another example of a regenerative brake module shown in a standard brake operation mode.

FIG. **8** is the regenerative brake module of FIG. **7** in a lower pressure, regenerative brake operation condition.

FIG. **9** is the regenerative brake module of FIG. **7** in a mid-pressure, regenerative brake shutdown sequence.

FIG. **10** is the regenerative brake module of FIG. **7** in high pressure, regenerative brake override condition.

FIG. **11** is a schematic representation of a bypass valve combining stage one and stage two valves that can be used in a regenerative brake module as shown in FIGS. **7-10**.

FIG. **12** is the bypass valve of FIG. **11** with a pressure regulator blocked condition and with stage one closed, which corresponds to FIG. **9**.

FIG. **13** is the bypass valve of FIG. **11** with a pressure regulator blocked condition and with the stage two valve open to provide a bypass flowpath as shown in FIG. **10**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A braking system **10** for a hybrid vehicle includes a primary brake circuit **12** for a rear axle **14** and a secondary brake circuit **16** for a front axle **18**. The exemplary hybrid vehicle includes a drive system with an electric motor and combustion engine that cooperate to propel the vehicle; however, in alternate embodiments other hybrid vehicles (for example, hydraulic hybrids and spinwheel hybrids), and electric vehicle configurations may utilize the brake circuit described herein. The rear axle **14** includes a set of rear wheels **20** and the front axle **18** includes a set of front wheels **22**. Each wheel **20**, **22** includes a wheel brake with an air chamber **24**. A front air supply reservoir **26** is fluidly connected to front air chambers **24** via fluid connections in the secondary brake circuit **16**. A rear air supply reservoir **28** is fluidly connected to rear air chambers **24** via fluid connections in the primary brake circuit **12**. An air dryer **30** is connected to the front **26** and rear **28** air supply reservoirs to reduce the moisture content of the air being supplied to the reservoirs.

A control valve **32** is fluidly connected to the primary **12** and secondary **16** brake circuits. The control valve **32** can also be optionally fluidly connected to a tractor protection valve **34** and trailer brake system **36**. A brake input member, such as a brake treadle **38** for example, is connected to the primary **12** and secondary **16** brake circuits, as well as being connected to the control valve **32**. A vehicle operator can press down on the brake treadle **38** to initiate a braking request. The braking system **10** may also include a separately actuated parking brake **40** that can be selectively actuated by the vehicle operator.

The braking system **10** includes a regenerative brake module **50** for each of the front **18** and rear **14** axles. The regenerative brake module **50** for the rear axle **14** is associated with a rear relay valve **52** that is part of a brake relay circuit. The regenerative brake module **50** for the front axle **18** is the same as the module for the rear axle; however, the brake module **50** additionally includes a front relay valve **54** not present in the exemplary secondary brake circuit **16**.

One example of the regenerative brake module **50** is shown in greater detail in FIGS. **2**-**6**. As shown in FIG. **2**, the brake treadle **38** forms part of a treadle circuit that includes a first treadle valve **56** for the primary brake circuit **12** and a second treadle valve **58** for the secondary brake circuit **16**. In the example shown, a regenerative brake module **50** for the rear axle **14** is shown, with the first treadle valve **56** being fluidly connected to the rear air supply reservoir **28**. It should be understood that operation of the regenerative brake module **50** for the front axle **18** would be the same as shown for the rear axle but would be connected through the second treadle valve **58**.

A first pressure sensor **60** measures a requested brake pressure generated by the vehicle operator pressing down on the brake treadle **38**. A control valve comprising a 3/2 valve **62** for example, is downstream of the first pressure sensor **60**. The 3/2 valve **62** is in a normally open position and is operable to move to a closed position to block airflow to vehicle foundation brakes, i.e. to block direct flow to the rear relay valve **52**. An electronic pressure regulator valve **64** connects to the 3/2 valve **62** when in the closed position to allow venting. The electronic pressure regulator valve **64** provides a fluid connection between the rear air supply reservoir **28** and the rear relay valve **52** positioned upstream of the rear air chambers **24**.

An electronic control unit **66** receives the vehicle operator brake pressure request, i.e. a treadle pressure input signal **68**, and compares the requested brake pressure to an available amount of regenerative brake torque that can be provided by an alternative power source **70**, such as an electric generator for example. A determination of available regenerative braking can take into account parameters such as vehicle speed, passenger ride preference, the brake request, the regenerative capacity of the vehicle, energy storage state-of-charge or equivalent, and various powertrain and engine characteristics. Although an exemplary embodiment is described in which the electronic control unit **66** determines an 'available regenerative braking' it is to be understood the electronic control unit can determine a target regenerative braking level based on based on vehicle parameters that is less the maximum available regenerative braking level and control the vehicle based on the target regenerative braking level. For example, the target regenerative braking level may be less than the available regenerative braking during transient conditions such as a shift event. The electronic control unit **66** can determine an amount of foundation brake pressure based on the available regenerative braking level, for example to supplement regenerative braking to generate a desired total brake torque. The electronic control unit **66** generates a control signal based on the determined foundation brake level to command the 3/2 valve **62** to the closed position thereby connecting the electronic pressure regulator valve **64** to the reservoir and providing desired foundation brake pressure needed to the rear relay valve **52** of the brake relay circuit.

In one example, a vehicle operator generates a brake request measured by the first pressure sensor at 30 psi. The electronic control unit **66** determines how much total braking torque is being requested by translating the pressure signal to a brake torque output, for example 1000 Nm by modeling or using a lookup table. The control unit **66** determines the available regenerative braking torque and determines a supplemental foundation brake level based on the brake torque output and the available regenerative braking torque. This torque requirement is translated back to a reduced brake application pressure by the electronic control unit **66** and is delivered by the pressure regulator **64** from the reservoir to the wheel brakes via relay valve **52** and the air chambers **24**. For example, if the request is 1000 Nm and the available regenerative torque is 200 Nm, then the foundation brakes will supply the remaining 800 Nm. The calculation of total brake torque versus treadle pressure requires a known number of braking units and does not take into account trailer brakes, which comprise a variable braking source. Application of this regenerative brake module **50** to the trailer brake air circuit would also be possible if the number of trailer brakes were determined.

At least one pressure-piloted valve **72** selectively provides fluid communication between the treadle **38** and the relay valve **52** when the requested brake pressure is greater than a predetermined (override) value limit, i.e. a mechanical bypass is provided to quickly and efficiently accommodate aggressive braking requests. In one example, a second pressure sensor **86** is included that measures a delivered brake pressure to the relay valve and communicates the delivered brake pressure to the electronic control unit **66** to provide a closed-loop system.

Thus, the first pressure sensor **60**, second pressure sensor **86**, the 3/2 valve **62**, the pressure-piloted valve **72**, the electronic pressure regulator valve **64**, and the electronic control unit **66** cooperate to form the regenerative brake module **50**. The regenerative brake module **50** is switchable between a system "off" condition and a system "on" condition depending on various factors such as an amount of braking requested, vehicle speed, road conditions, etc.

FIG. **3** shows an example of the regenerative brake module **50** being in the system off condition. For example, the control module can determine and command the system off condition when a stability control event (ABS, traction control, etc.) is detected, at slow speed, when the energy storage devices are at a maximum state of charge, or when a system fault is detected. In the system off condition the 3/2 valve **62** is normally open such that air can flow through the 3/2 valve **62**, to the pressure regulator **64**, and to the relay valve **52** (as indicated by flowpath **74**). At pressures that exceed the predetermined limit, the pressure piloted valve **72** opens a secondary flowpath **76** to fluidly connect the pressure to the relay valve **52**. In the off state both flowpaths are available depending on the treadle pressure. The pressure regulator valve **64** is connected to the supply reservoir **28** as indicated at **78**. Thus, in this system off condition, there is standard air brake operation with all electronic valves being normally open for control pressure and a mechanical bypass valve being normally closed but which can provide a secondary flow path in response to pressures exceeding a predetermined limit.

FIG. **4** shows the system on condition, which typically corresponds to a situation where low pressure (pressure below the predetermined limit) braking is requested. In the system on condition (regenerative braking active) the treadle pressure is blocked by the 3/2 valve **62** and the electronic control unit **66** reads this treadle pressure as a braking request. The electronic control unit **66** then generates a command signal which is communicated to the pressure regulator **64** to provide an alternate pressure, i.e. the control unit **66** modifies the treadle circuit request.

When this occurs, the 3/2 valve **62** is moved to the closed position, as shown in FIG. **4**, to block air flow from the treadle circuit and to open an exhaust path **82** through the pressure-piloted valve **72** for the electronic pressure regulator **64** to utilize during delivery of the pressure required by the electronic control unit **66**. The electronic pressure regulator valve **64** delivers pressure from the reservoir connection **78** to the relay valve **52**. The pressure-piloted valve **72** remains closed in this condition to isolate the requested treadle pressure from the pressure signal delivered by the electronic pressure regulator **64**.

A second pressure sensor **86** is positioned downstream of the pressure regulator valve **64** and upstream of the relay valve **52** to measure the pressure being delivered to the relay valve **52**. Thus, in the system on condition a commanded pressure is delivered from the supply reservoir **28** via the electronic pressure regulator **64** to the relay valve **52**, a vent path is provided for the pressure regulator valve **64**, and the delivered brake pressure is monitored by the second pressure sensor **86** to provide closed loop control. Further, in the event of a full holdoff, the air brakes can be "prepped" at a crack pressure.

FIG. **5** shows the regenerative brake module **50** in a "push through" braking condition, which would occur during a high pressure (above predetermined pressure limit) braking event, i.e. aggressive or panic stopping. In response to an aggressive braking request, the electronic control unit receives the high pressure signal from the pressure sensor **60** and cancels regenerative braking operation, returning the 3/2 valve to its normally open position, and communicates the treadle pressure through the electronic pressure regulator **64** to the relay valve **52**. In addition, the pressure-piloted valve **72** moves to a secondary position where air flow is communicated through the pressure-piloted valve **72** to a location downstream of the electronic pressure regulator valve **64** (as indicated by flowpath **88**). Further, air flow venting from the 3/2 valve **62** is blocked by the pressure-piloted valve **72** (as indicated at **90**) such that all available pressure generated by the treadle is communicated directly to the relay valve **52**. The redundant operation of blocking the exhaust port serves to alleviate any inadvertent venting of the treadle pressure if the system could not react fast enough during a panic stop or failed to cancel the regenerative braking mode for some reason.

Thus, if the system is in the "on" condition and a vehicle operator initiates a panic stop, the treadle pressure overpowers the pressure-piloted valve **72** and the pressure-piloted valve **72** blocks the vent option of the pressure regulator valve **64**. In other words, in this situation the treadle pressure signal overrides electronic control and the treadle pressure is sent directly to the relay valve **52**. As discussed above, the second pressure sensor **86** measures the delivered brake pressure supplied to the relay valve **52** and communicates the delivered brake pressure to the electronic control unit **66** to provide a closed-loop system. If the first pressure sensor **60** or the second pressure sensor **86** reads a pressure in excess of the predetermined limit, i.e. the pressure limit of the pressure-piloted valve **72**, when the pressure-piloted valve **72** is moved to the bypass position, the pressure sensor **86** communicates the pressure data to the electronic control unit **66** to cancel the control (system on) mode and revert to a system off condition.

The regenerative brake module **50** also incorporates a fault sensing condition. During normal operation, when the system is in the off condition, the first **60** and second **86** pressure sensors read the same pressure. If the sensors read different pressures, this can be used to detect possible valve failures. If one of the sensors fails, for example if the treadle pressure sensor (first pressure sensor **60**) fails, the second pressure sensor **86** would still be capable of reading the requested pressure. Any difference between a failed delivery sensor and the pressure regulator valve **64** (associated with the second pressure sensor **86**) can be used in a perturbation test to determine a cause of the failure. As such, a double component failure is required to lose each brake circuit operation.

FIG. **6** shows another example of a regenerative brake module **50'**. This configuration is similar to that of FIGS. **2-5**; however, the pressure-piloted valve **72** is separated into two pressure control valves. A first pressure piloted valve **100** is operable to bypass the 3/2 valve **62** when pressure exceeds a first predetermined limit, which would occurring during an event as described above with regard to FIG. **4** or **5**. A second pressure-piloted valve **102** is operable to block pressure from exhausting from the 3/2 valve **62** when pressure exceeds a second predetermined limit, which would occur during an aggressive braking request as described above with regard to FIG. **5**. The first and second predetermined limits are set to a common pressure which would be within the range of 20-50 psi, for example.

In an optional embodiment, the brake module **50** can include an additional check valve, schematically indicated at **80**. This valve **80** would be operational only during a failure mode as described below. In the system "on" condition, if the pressure regulator **64** fails to switch off when treadle pressure exceeds the override limit, i.e. when the bypass valve is tripped, then there is a condition where two pressure regulators would be fighting for control. For this reason, the valve **72** is configured to block the exhaust path such that the valve does not allow the pressure regulator **64** to vent treadle pressure back to the control unit's commanded value, i.e. a lower pressure.

However, the valve may still attempt to ventilate. In a situation where treadle pressure exceeds the override limit and continues to increase, the pressure regulator **64** may try to vent what is considered to be excessive downstream pressure, which fills the blocked vent air passage with high pressure air. As treadle pressure begins to decrease, but is still higher than the override limit, the high pressure air is still trapped behind the pressure regulator **64**. This results in application of an unbalance load on the pressure regulator valve **64** and serves as a mechanical mechanism to request more pressure from the regulator. The result is that the regulator will start to deliver pressurized air from the reservoir as pressure from the treadle is decreasing, causing a backflow through the treadle. Adding the check valve **80** allows this pressure to escape in this failure state and prevents backflow. If the check valve **80** is not included, the system may have a lag in brake release timing if the control unit **66** does not properly cancel out of the regenerative braking mode in this particular failure mode.

Another example of a regenerative brake module **200** is shown in FIGS. **7-10**. This configuration is similar to that of FIGS. **2-5**; however, the mechanical bypass, i.e. the pressure-piloted valve **72** comprises a valve **202** that includes a stage one valve **204** and a stage two valve **206**.

FIG. **7** shows a configuration that corresponds to a system "off" mode which occurs during standard braking operations. In this mode, the 3/2 valve **62** is in a normally open position and fluidly connected to the relay valve **52** through the pressure regulator valve **64**, which is also in a normally open position. As such, treadle pressure from a treadle circuit is communicated directly to the relay valve **52** in a relay circuit of the brake system to allow standard braking to occur in response to braking requests input to the treadle **38**.

FIG. **8** shows a configuration for a system "on" condition that comprises a first mode of operation. This first mode of operation is for braking requests that comprise a low pressure condition, i.e. requested pressures are below a predetermined limit such as 20-50 psi for example. In this mode of operation, the 3/2 valve **62** is moved to a position that blocks treadle pressure and opens an exhaust path **210** for the 3/2 command valve to the stage one valve **204**. As such, air can be exhausted through the regulator valve **64**, through the 3/2 valve **62** and out through the stage one valve **204**. The stage two valve **206** continues to block access to the treadle circuit.

The first pressure sensor **60** reads the command pressure, i.e. the pressure requested as a result of an input to the treadle **38**, and communicates this pressure to the electronic control unit **66**. The control unit **66** determines how much regenerative braking can be supplied and then determines how much air pressure to deliver from the reservoir **28** to supply any remaining pressure needed. As such, the requested pressure, instead of being wholly supplied via the reservoir as occurs in standard operation, is supplied as a combination of regenerative braking and a reduced amount of reservoir air pressure. Thus, the air pressure delivered to the relay valve **52** is less than the command pressure. The second pressure sensor **86** measures the pressure supplied to the relay valve **52** and communicates this measured pressure back to the control unit **66** to establish a closed loop control of delivery pressure.

FIG. **9** shows another mode of operation that corresponds to a mid-pressure, regenerative brake shutdown sequence. This occurs at pressures that exceed the predetermined pressure limit set for the FIG. **8** configuration, but which are less than an override limit that would be set for a panic or aggressive brake request such as that which will be discussed with regard to FIG. **10**.

In the mid-pressure mode of operation, initially the 3/2 valve **62** blocks the treadle pressure and the stage two valve **206** is also in a blocking position. The stage one valve **204** also moves to a blocking position to block the exhaust path **210** from the regulator valve **64** and 3/2 valve **62**. Initially, the braking supplied to the wheel **20** is a blend of regenerative braking and a reduced air pressure, i.e. reduced compared to the command request, from the reservoir. However, in this mode, the control unit **66** blends out the regenerative braking such that the system will revert to the "off" mode as shown in FIG. **7** for standard brake operation. Thus, the 3/2 valve **62** will move from the blocking position shown in FIG. **9** back to a normally open position.

FIG. **10** shows a second mode of operation that corresponds to a high pressure, regenerative brake override condition. This would occur for a panic braking or aggressive braking request. In this configuration the stage one valve **204** blocks the exhaust path **210** and the stage two valve **206** moves to an open position, i.e. a bypass position, to directly connect the treadle circuit to the relay circuit, i.e. treadle pressure is directly supplied to the relay valve **52**. The control unit **66** has no capability to override the treadle pressure and the system returns to the "off" mode as shown in FIG. **7**.

In an optional embodiment, the brake module **200** can include an additional check valve, schematically indicated at **212**. This valve **212** would be operational only during a failure mode as described below. In the system "on" condition, if the pressure regulator **64** fails to switch off when treadle pressure exceeds the override limit, i.e. when the bypass valve **202** is tripped, then there is a condition where two pressure regulators would be fighting for control. For this reason, the stage one valve **204** is configured to block the exhaust path **210** such that the valve does not allow the pressure regulator **64** to vent treadle pressure back to the control unit's commanded value, i.e. a lower pressure.

However, the valve may still attempt to ventilate. In a situation where treadle pressure exceeds the override limit and continues to increase, the pressure regulator **64** may try to vent what is considered to be excessive downstream pressure, which fills the blocked vent air passage with high pressure air. As treadle pressure begins to decrease, but is still higher than the override limit, the high pressure air is still trapped behind the pressure regulator **64**. This results in application of an unbalance load on the pressure regulator valve **64** and serves as a mechanical mechanism to request more pressure from the regulator. The result is that the regulator will start to deliver pressurized air from the reservoir as pressure from the treadle is decreasing, causing a backflow through the treadle. Adding the check valve **212** allows this pressure to escape in this failure state and prevents backflow. If the check valve **212** is not included, the system may have a lag in brake release timing if the control unit **66** does not properly cancel out of the regenerative braking mode.

FIGS. **11-13** show the bypass valve **202** as used in the configuration shown in FIGS. **7-10**. This valve is also set forth and described in co-pending application Ser. No. 13/160,610, filed on even date herewith and assigned to the same assignee as the present invention, which is directed to the air braking system. The subject matter of Ser. No. 13/160,610 is herein incorporated by reference. The bypass valve **202** incorporates the stage one **204** and stage two **206** valves as discussed above.

The bypass valve **202** has a valve body **214** that includes a bore **216** that receives the stage one **204** and stage two **206** valves. The bore **216** has an enlarged bore portion **216*a*** of a maximum bore diameter at one valve end. A first reduced bore portion **216*b*** extends from the enlarged bore portion **216*a*** to a second reduced bore portion **216*c***. The stage one valve **204** is normally open and the stage two valve **206** is normally closed. The valve body **214** includes a 3/2 valve port **222**, a relay valve port **224**, a treadle port **226**, and an exhaust port **228** that exhaust out of the enlarged bore portion **216*a***.

A shaft **230** is fit within the valve body **214** in a sliding relationship and extends between a first shaft end **232** and a second shaft end **234**. A bore **236** is formed within the shaft **230** and extends from the first shaft end **232** to the second shaft end **234**. Fit within the bore **236** is a tube **238** that receives a plunger **240** at the first shaft end **232**. The plunger **240** has a stem or shaft portion that is slidingly received within the tube **238** and an enlarged head portion that extends out of the tube **238**. A seal **242** is received around the shaft portion and abuts against an underside of the enlarged head portion.

In the configuration shown in FIG. **11**, the system is in a low pressure mode such as that described above with regard to

FIG. **8**. The first shaft end **232** is seated against a first valve seat **244** formed at one end of the second reduced bore portion **216***c* and the plunger **240** is positioned such that the seal **242** is moved out of engagement with the shaft **230** to allow the pressure regulator **64** to connect to the exhaust path **210** via port **222**.

The shaft **230** also includes an enlarged flange portion **246** that supports a sealing member **248** for engagement with a second seal seat **250** formed at the transition between the first reduced bore portion **216***b* and the second reduced bore portion **216***c*. A resilient member **252** has one end **254** supported on a side of the flange portion **246** that is opposite of the sealing member **248** and an opposite end **256** that is seated against an insert member **258** that is fit within the enlarged bore portion **216***a*. The insert member **258** comprises a cup-shaped member having a base portion with an opening **260** through which the second shaft end **234** extends. A surface of the base portion surrounding the opening **260** provides a seat of the end **256** of the resilient member **252**.

Received within the insert member **258** is a piston **262** that also comprises a cup-shaped member. A piston head portion **264** of the piston **262** faces the base portion of the insert member **258** and includes an opening **266** to receive the tube **238**. A stem **268** surrounds the opening **266** and extends outwardly from the piston head portion **264** in a direction away from the base portion of the insert member **258**. The tube **238** extends through the stem **268**.

An end cap **270** is fit against the valve body **214** at an open end of the enlarged bore portion **216***a*. The end cap **270** includes an opening **272** for the exhaust path **210**. Surrounding the opening **272** is a lip **274** that extends inwardly toward the piston **262**. A resilient member **276** is seated within the piston **262**. One end **278** of the resilient member **276** is seated against the piston head portion **264** and an opposite end **280** of the resilient member **276** is seated against end cap **270** to surround the lip **274**.

As discussed above, FIG. **11** discloses a low pressure mode for the brake system. The 3/2 valve port **222** is open such that the pressure regulator **64** is free to use the exhaust path through the tube **238** and out the exhaust port **228**. As shown, the plunger **240** is moved out of engagement with the shaft **230** to open the exhaust path and the relay valve port **224** is blocked. The treadle port **226** that is connectable to the treadle circuit is inactive at low braking pressures. As such, the valve design provides a balanced configuration where performance is independent of the downstream relay valve pressure.

In FIG. **12**, the valve **202** is in a position that corresponds to the mode set forth in FIG. **9**. The plunger **240** is sealingly seated within the tube **238** and shaft **230** such that the pressure regulator **64** is blocked at the 3/2 valve port **222** from allowing exhaust flow out of port **228**. As such, the pressure regulator **64** is blocked from lowering the brake pressure and the control unit **66** is configured to blend out of the regenerative braking to return to standard brake operation. As shown, the stage one valve **204** has closed and the piston **262** has moved away from the insert **258**. This mode would occur at pressures that exceed a predetermined limit that would be within the range of 20-50 psi, for example.

In FIG. **13**, the valve **202** is in a position that corresponds to the mode set forth in FIG. **10**. The exhaust path is blocked via the plunger **240** at the 3/2 valve port **222**. The piston **262** has moved further away from the insert **258**, and the flange portion is unseated from the second valve seat **250**. This connects the treadle circuit directly to the relay circuit for an aggressive braking condition via the relay valve port **224** and the treadle port **226**. The electronic valves are therefore immediately bypassed and the control unit **66** cannot override the bypass valve **202** in this condition.

As shown and discussed, the various movements of the valve components occur in stages. The second stage **206** is normally closed, but as treadle pressure increases the valve is configured initially move the piston **262** away from the shaft end **234** to first blend out regenerative braking at mid-pressure ranges. As treadle pressure increases for an aggressive braking request, the shaft **230** is free to move the flange portion **246** away from the second valve seat **250** due to the compressed movement of the piston **262**. This directly connects the relay and treadle circuits.

The subject braking system **10** operates to provide computer controlled brake blending while maintaining appropriate mechanical safety features. As discussed above, brake treadle pressure is read by a pressure sensor and when the system is in the on condition, the pneumatic signal generated by the vehicle operator is blocked by the 3/2 valve, which is normally open. This valve simultaneously opens an exhaust/vent port for the proportional regulator valve that sends an alternative pressure command to the brake system. The regulator valve taps directly into the supply reservoir and delivers the alternate pressure signal from this supply. The second pressure signal reads the output pressure signal and closes the control loop on the delivery brake pressure. An alternative mechanical bypass exists that opens a self-piloted valve at a predetermined pressure to mechanically limit the regenerative braking zone to a lower range of the brake application range. This keeps regenerative operation in a low-g arrangement and voids vehicle dynamic influences.

In one example, two regenerative brake modules are used on each circuit in the vehicle. The redundancy of the two modules allows cross checking of the input pressure sensor. Examining both pressure sensors in each circuit can determine if there is a valve failure in-between, and a perturbation of the valve setting can examiner the delivery sensor function. This module can also provide ATC operation in place of an ATC valve.

Although an embodiment of this invention has been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

What is claimed is:

1. An air braking system for a vehicle comprising:

a treadle input configured to receive a brake request, the treadle input mechanically actuating a treadle valve of a treadle circuit having a treadle circuit air pressure;

a sensor that measures the brake request at the treadle circuit;

a controller configured to determine a control valve command based on the brake request from the sensor and based on a regenerative braking level;

a control valve configured to control a delivered air pressure level in a brake relay circuit based on the control valve command, wherein the brake relay circuit is configured to communicate the delivered air pressure level to a vehicle brake; and

a bypass valve that is operable to directly communicate treadle pressure to the brake relay circuit when requested brake pressure is greater than an override limit.

2. The air braking system according to claim **1** wherein the brake relay circuit includes a relay valve that communicates a delivered air pressure to the vehicle brake, and wherein the control valve is in a normally open position to directly connect the treadle circuit and the relay circuit during a first mode of operation, and wherein the control valve is operable to block treadle pressure in a second mode of operation.

3. The air braking system according to claim **2** including an electronic pressure regulator configured to communicate treadle pressure to the relay valve when in the first mode of operation and configured to communicate an air pressure less than the treadle pressure when in the second mode of operation.

4. The air braking system according to claim **3** wherein the controller is configured to generate a control signal based on the requested brake pressure and an available amount of regenerative braking, the control valve and electronic pressure regulator operating in the first or second mode of operation in response to the control signal to communicate the delivered air pressure to the vehicle brake.

5. The air braking system according to claim **2** wherein the bypass valve directly communicates treadle pressure to the relay valve when the requested brake pressure is greater than the override limit.

6. The air braking system according to claim **2** wherein the control valve comprises a 3/2 valve.

7. The air braking system according to claim **1** wherein, when operating in a first mode, the controller commands pressure to vehicle brakes at a different pressure than that requested by the treadle valve such that regeneration compensates for at least a portion of the brake request.

8. The air braking system according to claim **7** wherein, when operating in a second mode, air flows directly between the treadle circuit and the brake relay circuit to allow direct control of the delivered air pressure level by treadle valve pressure.

9. The air braking system according to claim **1** wherein the controller is configured to determine the brake request based on treadle valve pressure.

10. The air braking system according to claim **1** wherein the controller is configured to:

receive a pressure signal measured in the treadle circuit, to determine an available regenerative braking level, and to determine the control valve command based on the pressure signal and the available regenerative braking level.

11. The air braking system according to claim **1** wherein, when treadle circuit air pressure falls below a predetermined pressure, the control valve allows direct air flow between the treadle circuit and the brake relay circuit.

12. The air braking system according to claim **1** wherein direct air flow is provided between the treadle circuit and the brake relay circuit in response to a system fault detection or when a high deceleration brake request.

13. The air braking system according to claim **1** wherein the regenerative braking level is based at least on one or more of the following parameters including vehicle speed, brake request, energy storage state-of-charge, and engine characteristics.

14. An air braking system for a vehicle comprising:

a treadle circuit including a treadle valve associated with a treadle input that is actuated in response to a brake request;

a first pressure sensor that measures a requested brake pressure from the treadle valve;

a relay circuit including a relay valve that communicates a delivered air pressure to a vehicle brake;

a control valve in a normally open position to directly connect the treadle circuit and the relay circuit during a first mode of operation, and wherein the control valve is operable to block treadle pressure in a second mode of operation;

an electronic pressure regulator configured to communicate treadle pressure to the relay valve when in the first mode of operation and configured to communicate an air pressure less than the treadle pressure when in the second mode of operation;

a controller configured to generate a control signal based on the requested brake pressure and an available amount of regenerative braking, the control valve and electronic pressure regulator operating in the first or second mode of operation in response to the control signal to communicate the delivered air pressure to the vehicle brake; and

a mechanical bypass valve that is operable to directly communicate treadle pressure to the relay valve when the requested brake pressure is greater than an override limit.

15. The air braking system according to claim **14** wherein:

when in the first mode of operation, the delivered air pressure is the treadle pressure; and

when in the second mode of operation, the delivered air pressure is an air pressure that is less than the treadle pressure.

16. The air braking system according to claim **15** wherein the first mode of operation comprises a system "off" mode for standard air brake operation and wherein the second mode of operation comprises a system "on" mode for regenerative braking operations at a condition where the requested brake pressure is less than a predetermined limit.

17. The air braking system according to claim **16** wherein the bypass valve is in a closed position when operating in the first mode of operation, and wherein the bypass valve is moveable to provide an exhaust path when in the second mode of operation such that air can be exhausted through the electronic pressure regulator, through the control valve, and out of the bypass valve.

18. The air braking system according to claim **17** including a second pressure sensor that measures the delivered air pressure to the relay valve and communicates the measured delivered air pressure to the controller to provide closed loop control.

19. The air braking system according to claim **18** wherein when the requested brake pressure is greater than the override limit the bypass valve is configured to block the exhaust path and directly connect the treadle pressure at a location upstream of the control valve to the relay valve at a location that is downstream of the electronic pressure regulator.

20. The air braking system according to claim **17** wherein the predetermined limit comprises a low pressure condition and including a third mode of operation where the requested brake pressure is greater than the predetermined limit and less than the override limit to comprises a mid-pressure operating condition, and wherein, when in the third mode of operation, the bypass valve is configured to block the exhaust path and the controller is configured to blend out regenerative braking to revert back to the first mode of operation.

21. The air braking system according to claim **14** wherein in response to a system fault detection the treadle pressure is communicated directly to the relay valve.

22. A method of controlling an air brake system for a vehicle comprising:

initiating a brake request by actuating a treadle input associated with a treadle valve in a treadle circuit;

measuring a requested brake pressure from the treadle valve with a first pressure sensor;

providing a relay valve circuit to communicate a delivered air pressure to a vehicle brake via a relay valve;

providing a control valve that is in a normally open position to directly connect the treadle circuit and the relay circuit during a first mode of operation;

configuring the control valve to block treadle pressure in a second mode of operation;

configuring an electronic pressure regulator to communicate treadle pressure to the relay valve when in the first mode of operation, and to communicate an air pressure less than the treadle pressure when in the second mode of operation;

generating a control signal based on the requested brake pressure and an available amount of regenerative braking, with the control valve and electronic pressure regulator operating in the first or second mode of operation in response to the control signal to provide the delivered air pressure;

communicating the delivered air pressure to the vehicle brake via the relay valve; and

directly communicating treadle pressure to the relay valve when the requested brake pressure is greater than an override limit via a mechanical bypass valve.

23. The method according to claim **22** wherein, when in the first mode of operation, the delivered air pressure is the treadle pressure, and when in the second mode of operation, the delivered air pressure is an air pressure that is less than the treadle pressure and including:

defining the first mode of operation as a system "off" mode for standard air brake operation; and

defining the second mode of operation as a system "on" mode for regenerative braking operations at a condition where the requested brake pressure is less than a predetermined limit.

24. The method according to claim **23** including closing the bypass valve when operating in the first mode of operation, and moving the bypass valve to provide an exhaust path when in the second mode of operation such that air can be exhausted through the electronic pressure regulator, through the control valve, and out of the bypass valve.

25. The method according to claim **24** including measuring the delivered pressure to the relay valve with a second pressure sensor, and communicating the measured delivered pressure to the controller to provide closed loop control.

26. The method according to claim **25** wherein the predetermined limit comprises a low pressure condition and including a third mode of operation where the requested brake pressure is greater than the first predetermined limit and less than the override limit to comprise a mid-pressure operating condition, and including:

blocking the exhaust path via the bypass valve when in the third mode of operation; and

blending out regenerative braking to revert from the third mode of operation to the first mode of operation.

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